Sustainable Ecosystems Institute

Review of Comprehensive Sturgeon Research Program

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Review of Comprehensive Sturgeon Research Program

Science Review Panel

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Sustainable Ecosystems Institute is a non-partisan organization of scientists dedicated to using their technical expertise to solve ecological problems. Headquartered in Portland, Oregon, the Institute works nationally and internationally. SEI specializes in independent scientific review. Visit http:// sei.org and http:// sei.org/peerrev.html for more details. Contact SEI at sei@sei.org

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EXECUTIVE SUMMARY OF KEY FINDINGS AND RECOMMENDATIONS

This report provides an external review of the US Geological Survey (USGS) Columbia Environmental Research Center's (the Center or CERC) Comprehensive Sturgeon Research Program (CSRP). The focus is to help ensure that the USGS research is technically sound, scientifically defensible, and policy relevant. An additional focus is to recommend (if warranted) any changes or adjustments in the approach.

OVERALL PROGRAM

KEY FINDINGS

The Center has provided the US Army Corps of Engineers (Corps) and the Missouri Basin with an excellent conceptually-driven and policy-relevant research effort. This is largely due to the high quality of the scientists engaged in the effort, and their approach. The program is an important anchor for the Center. Stakeholders benefit from being able to draw on this stable resource.

A strategic research approach has helped the Center researchers coalesce into a strong science team. CSRP is currently implemented by a group of talented and highly-motivated and collaborative researchers. CSRP scientists collaborate widely with scientists from other organizations. They have reached out to students and post docs were possible, and are building a good publication record.

The panel acknowledges the innovative approach of the Center in responding to the science needs of the Missouri River, and also the effort of the Corps to ensure that policy-relevant science is carried out.

RECOMMENDATIONS

There is a need for better and more formal communication among funders, stakeholders and the Center. This is required to provide faster access to science, to facilitate identification of science needs, and ways to incorporate results into policy and management.

Program Transition: CERC scientists and their collaborators have made significant and useful progress. But it is time for the program to move beyond an initial discovery phase. Scientists can pursue a more focused hypothesis driven approach, consulting with the clients, to ensure that all parties agree on what are the relevant hypotheses to move the restoration program forward. The Center is well positioned to provide scientific research.

To enhance the reputation of the program, and to make the information more widely available, the panel recommends that researchers broaden their range and visibility of journals in which they publish their results.

The methodology for funding the program hinders full implementation of a strategic research effort. Multi-year and strategic funding to CSRP would overcome this. Funding to attract post-docs and students would also benefit the investigation program and therefore the production of useful results for management of the River. Additionally the panel recognizes the value of a broader, more basin-wide research and funding program that is strategic, inclusive, and coordinated.

On a basin-wide scale, absent a formal process for the use of science in decision making, there exists the real possibility of science entering the policy arena in a haphazard way. This is likely to lead to confusion and conflict rather than constructive dialogue and resolution. Indeed such situations have already arisen in the history of science-policy in the basin. A formal process is urgently needed. That process should be transparent, science-based, facilitated, and ongoing.

SCIENTIFIC PROGRAMS

FINDINGS

The research strategy of the CERC to target questions central to current management priorities has produced valuable findings.

The approach of integrating field and laboratory studies into one research program has yielded findings that would be difficult to obtain by individual investigations.

Two defining design features of the research program are hydrologic, telemetry-linked studies and use of a surrogate species.

Documenting spawning of both shovelnose and pallid sturgeon in the Missouri River is a notable achievement, as this life event is difficult to capture in the field, particularly for less abundant pallid sturgeon.

A range of spatial scales have been explored to seek relations between sturgeon behavior and the river environment, yielding some significant findings, and much of the lower river has been covered in some way.

The use of shovelnose sturgeon as a surrogate species in the research has been productive for refining capture and tagging methods, designing efficient telemetry tracking, perfecting techniques for reproductive assessment, and other gains in study effectiveness.

RECOMMENDATIONS

Strive to move beyond a research effort that responds only to immediate management-generated questions, to provide leadership on identifying study and data needs.

Continue to develop a research strategy of telemetry-based studies and surrogate species use as a model for making scientific contributions to endangered species recovery.

Expand the river coverage included in the intensive telemetry-based studies by investigating new life stages and river habitats, as effort can now be reduced on the present priorities.

Review and communicate the uses and limitations of shovelnose sturgeon as a surrogate species for pallid sturgeon in Missouri River research and management.

Develop a phased plan for future research covering all life stages of pallid sturgeon and build in points where the concept of an early life constraint can be evaluated.

Develop a model of how habitat conditions can be linked to sturgeon movements at a range of scales with data needs across scales to identify key species-habitat combinations.

Summarize the constraints imposed and opportunities remaining for identifying species-habitat links in a system that has been greatly modified and fragmented.

Consider habitat illumination by reduced turbidity as a limiting factor on pallid sturgeon habitat, taking advantage of the USGS expertise in monitoring fine-sediment transport and resulting water quality.

PHYSIOLOGY

FINDINGS

Reproductive physiology is a key component of the project with endangered pallid sturgeon. The members of the USGS reproductive physiology team are highly qualified scientists.

In collaboration with an excellent team of hydrologists, physiologists developed a unique interdisciplinary, mission-oriented project with endangered pallid sturgeon.

The more abundant shovelnose sturgeon has been used as a “surrogate” species for the development of reproductive assessment techniques, justified by the morphological and ecological similarities.

The panel notes excellent publications on reproductive assessment of shovelnose but recommends strengthening several scientific approaches and following up on new methods that are yielding positive results.

RECOMMENDATIONS

Diagnostic techniques for reproductive assessment of shovelnose can be used for the pallid sturgeon. We suggest focusing further efforts on the reproductive cycle of the target species, using wild and captive stocks of pallid sturgeon.

The proposed conceptual model for reproductive physiology of pallid sturgeon is based on the interaction of reproductive hormones, LH and MIH, and environmental cues in the late phase of reproductive cycle. For full assessment of reproductive efficiency of the pallid sturgeon, the panel recommends including the early phase of ovarian cycle and the secretion of FSH. This will be a novel development in reproductive assessment of sturgeon and may contribute to visibility of the USGS project

Research with captive stocks has contributed much to our current knowledge of reproductive physiology of fish. We recommend expanding research on reproductive physiology, using captive stocks of pallid sturgeon.

The panel notes that studies on reproductive physiology of sturgeon require adequate and stable funding support. It feels that this support is warranted and would be a strong investment as such studies provide unique insight into environmental impact on reproduction of sturgeon.

STURGEON ECOLOGY

FINDINGS

Research on reproductive ecology, migration, and habitat requirements at CERC is being undertaken by highly dedicated and productive scientists. Team work is very evident with a strong motivation to do relevant science.

The CERC team has moved aggressively towards both innovation in technology and modeling, but has been strategic about data analysis and scientific context.

The linked reproductive-telemetry study is unique for studies on fish migration, and has contributed to important discoveries on pallid sturgeon reproduction. Similarly, a very ambitious ichthoplankton program has shown that it may be feasible to conduct early life history studies on pallid sturgeon.

Some approaches have not yet worked or been effectively deployed. These include lack of identification of pallid sturgeon larvae in the current icthyoplankton program, lack of a deployed telemetry receiver array, and unsuccessful visualization of spawning behavior through DIDSON.

With the success of pallid sturgeon collections, the panel recognized a potential conflict in the use of spawners for either research or hatchery-based restoration. Currently, the allocation of spawners towards hatchery use is given a much higher priority by the Pallid Sturgeon Recovery Team.

Shovelnose sturgeon have been effectively used in developing successful approaches related to telemetry, larval collections, and habitat choice models.

RECOMMENDATIONS

The Panel recommends that all larval collections be put in ethanol and sufficient resources be allocated towards genetic and taxonomic identification of larval pallid sturgeon.

Programmatic concerns have curtailed deployment of a receiver array. Because important benefits of a receiver array will accrue only with multi-year deployments, a different funding mechanism to CERC may be appropriate.

The DIDSON application may be important for media and public outreach, but the panel deemed it less important to the future of the research effort than deployment of the lower Missouri telemetry array and continued ichthyoplankton sampling and identification of larval pallid sturgeon.

Hatchery field experiments represent a powerful means to engage questions about larval spatial and demographic fates. In larger systems such as the lower Missouri River, larval release experiments can be simulated with hydrological models and then potential larval and juvenile nursery habitats can be "probed" through hatchery release experiments. Further, hatchery fish are efficiently deployed in a variety of lab and pond experiments related to habitat preference, feeding, and species interactions.

Although hatcheries have been a boon in provision of research animals, current demands are over-taxing the CERC telemetry program. Too few collected spawners are allowed to be tagged and returned to permit rigorous examination of flow and habitat requirements for spawning. One option might be to allocate spawners between years that are designated as entirely research- or hatchery-allocation years.

Past use of shovelnose sturgeon as a surrogate species has been very useful, but past successes strongly suggest that the program can and should place greater emphasis on pallid sturgeon reproduction and habitat requirements to more effectively utilize limited research funds.

HYDROLOGY AND GEOMORPHOLOGY

FINDINGS

CERC has invested a skillful, energetic team of physical scientists in the sturgeon project, and they have made an exceptional effort to conduct studies of physical habitat characteristics in a manner that is tightly linked to the fish studies.

Much progress has already been made in high-quality measurements of environmental conditions within the heavily altered Missouri River channel and to model the details of flow conditions over spawning habitat for a range of discharge.

Geomorphological studies of spawning gravel distributions, shallow water habitats, and floodplain channels are broadening the information base for future studies of other life stages of the sturgeon.

The interdisciplinary nature of the USGS, its ability to invest first-rate scientific talent and equipment, its network of science centers, and its unique relationships with state agencies gives them a powerful advantage in providing conceptual, logistical, and analytical leadership for large-scale, interdisciplinary and inter-state assessments.

RECOMMENDATIONS

The excellent work already done in topographic survey of channels and in flow modeling could be extended to form the basis experimental studies of the dispersal and survival of the fish at post-spawning life stages.

The group has a very good record of producing scientific publications, and surveys and data reports for planning, but provision of more postdoctoral personnel to assist with analyzing the rich data stream being produced would extend the group’s productivity and usefulness to management agencies.

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INTRODUCTION

Sustainable Ecosystems Institute (SEI) is a public benefit, non-profit organization, founded in 1992. The goal of the Institute is to provide impartial scientific support for conservation decisions; the Institute is non-partisan, and seeks science-based, cooperative solutions to environmental issues. The organization has previously carried out extensive work on endangered species conservation and management, and has developed the use of peer review in such situations (Brosnan 2000).

SEI was contracted by USGS to review the Comprehensive Sturgeon Research Program (CSRP). This program is designed to study the factors affecting the reproduction and survival of pallid sturgeon and shovelnose sturgeon in the Missouri River. It is administered and carried out by scientists at Columbia Environmental Research Center (CERC), and collaborators elsewhere.

Major goals of this independent scientific review were to: assess whether the stated goals of CSRP are achievable, evaluate whether the scientific approach of CSRP is technically sound and scientifically defensible, determine if the scientific methods employed are valid and technologically advanced (and recommend adjustments or improvements that can be made to enhance the applicability or scientific validity of the Program).

The specific charges of SEI to the reviewers were:

- The panel will review the scientific approach of CSRP to ensure it is technically sound and scientifically defensible based on current national scientific standards and methods. Identify improvements or enhancements that would improve the technical merit of the research program.
- Determine whether the scientific methods employed are valid and technologically advanced.
- Establish if there are more modern methods, techniques or practices that CSRP has overlooked that would improve performance and scientific advancement.

- Resolve how often methods should be reviewed in the future.
- Recommend adjustments or improvements that can be made to enhance the applicability or scientific validity of the Program.
- Recommend changes or adjustments to the scientific approach used in CSRP
- Determine if any limitations are present that are beyond CSRP control to address.
- Provide evidence, documentation or other resources that were used to develop the recommendations.
- The review will also evaluate the CSRP in relation to the broader efforts of the Corps of Engineers in restoration of the Missouri river; addressing whether CSRP is complementary to these efforts, and provides a needed scientific framework for other programs such as those dealing with monitoring and habitat.

The overall goal of this review then is to provide a comprehensive, and critical evaluation of all information regarding the CSRP program as it applies to important science issues on the Missouri River. Ultimately, this evaluation may be used by USGS and partner agencies on the river in making management decisions. These are appropriately the responsibility of the various agencies. SEI's process is designed to provide an impartial scientific evaluation of the program at the Center. Our approach is restricted to summarizing, critiquing, analyzing, and synthesizing scientific materials.

The process we adopted was to set up a panel of experts drawn from a range of different academic backgrounds relevant to the review. These experts read the materials that were available or that were developed. Through a site-visit and other discussions, we evaluated the strengths and weaknesses of the various methodologies, practices and opinions. We also sought out the opinion of partner agencies on the success of the Center's program.

The site visit was held at Columbia Environmental Research Center in Columbia, Missouri January 31st through February 3rd, 2008 (See Appendix A for agenda).

Overall project lead was Dr. Steven Courtney, Vice-President of SEI, who has expertise in endangered species research and management, and in the application of peer review processes to natural resource management issues. Ms. Lisa Sztukowski was project manager; she also has extensive experience with endangered species management issues.

Panel members and their particular expertise in the review were:

• Dr. Deborah Brosnan (chair)	SEI	Governance; policy relevant science
• Dr. Mark Bain	Cornell	Sturgeon ecology; river ecosystems
• Dr. Serge Doroshov	UC Davis	Sturgeon reproductive physiology
• Dr. Tom Dunne	UC SB	River hydrology and geomorphology
• Dr. David Secor	U Maryland	Sturgeon ecology

Panelists were selected by SEI to represent a range of necessary and relevant academic disciplines. All panelists are recognized leaders in their fields of enquiry, and have records of providing impartial advice. In addition, SEI ensured that the panel had no conflict of interests, and understood the importance of providing technical evaluations that could be used by both scientists and decision-makers.

CHAPTER 1. FINDINGS AND RECOMMENDATIONS OF THE OVERALL CSRP PROGRAM

PROGRAM BACKGROUND

Intensive management of the Missouri River for purposes of navigation, flood control and power generation has resulted in major physical changes to the river. These changes, which have altered hydrological and biological processes, have been associated with declines in several species including native fish. Additionally the introduction of non-native species into the river has exacerbated stress on native populations. Currently, three sturgeon species endemic to the Missouri and Mississippi River basins are widely regarded as particularly impacted. One of them, the pallid sturgeon is listed as endangered under the federal Endangered Species Act (ESA). Two species of birds, the least tern (endangered) and the piping plover (threatened) are also listed.

The US Fish and Wildlife Service (The Service) charged with administering the ESA has called for returning the River to more natural flows (USFWS Final Biological Opinion 2004). The intent is to recover endangered species and restore the ecosystem to as natural a state as possible, while balancing multiple needs. In 2000, the Service issued a jeopardy opinion (under Section 7 of ESA) against the Corps for the endangered pallid sturgeon. The accompanying Biological Opinion included several reasonable and prudent alternatives provided to the Corps to remove jeopardy. In 2003, the opinion was reviewed and amended, and it re-affirmed the jeopardy opinion for the pallid sturgeon. The Corps was charged with several research and monitoring tasks which included the following items relevant to this review:

> "Identify the causes for lack of reproduction, lack of recruitment, and hybridization and dependant on the limiting factor, initiate efforts to restore conditions that would restore reproduction, recruitment and minimize the occurrence of hybridization with the shovelnose sturgeon…"
>
> "Identify and map the location of gravel/cobble/rock substrates that may provide potential spawning habitat for sturgeon within the prioritized river segments…"
>
> "Incorporate modifications into channel training structure maintenance projects to maintain and improve aquatic habitat diversity…"
>
> "Participate with Service and partners to prioritize research needs and projects for the pallid sturgeon on an annual basis starting in 2000"

A multi-agency workshop convened in 2004 developed a list of research needs for pallid sturgeon recovery. These were later prioritized. Guided by these priorities, the US Geological Service (USGS) and collaborating agencies designed a research approach to study factors affecting the reproduction and survival of the pallid and shovelnose sturgeon in the Missouri River. The program is known as the Comprehensive Sturgeon

Research Program (CSRP). The scope of this review concerns the USGS CSRP program only. The focus is to help ensure that the USGS approach and research is technically sound and scientifically defensible, and recommend (if warranted) any changes or adjustments in the approach. The panel recognizes that many other agencies, organizations, and individual scientists are deeply engaged in policy-relevant research on the recovery of the Missouri River ecosystem, and the panel acknowledges their work. However it is outside the scope of this review to comment on that wider effort.

OVERALL PROGRAM: EVALUATION AND RECOMMENDATIONS

The USGS Columbia Environmental Research Center has provided the Corps and the Missouri Basin with an excellent conceptually-driven and policy-relevant research effort. This is largely due to the high quality of the scientists engaged in the effort, and their approach.

In 2003, the Corps provided the Center with a request for a research proposal to specifically address the following question: "What critical ecological factors contribute to successful pallid and shovelnose sturgeon reproduction and survival in the Missouri River?" The Center's response to this challenge was innovative. Gathering their scientists together, they developed a multi-disciplinary, team-based strategic approach. Their proposal also included a realistic statement of cost to the Corps. At a time when very little was known about the pallid sturgeon, the scientists created a conceptual model which was later refined into a more detailed version (See Chapter 2). Since that time the researchers have set about systematically investigating the key unknowns in the model. The creation of a conceptual model may seem an obvious first step to many academic scientists contemplating a science program. However, in situations when policy or a judicial ruling is the driver of research questions, many programs often fail to identify their conceptual models. This in turn hampers the research and its usefulness (Brosnan and Quinn 2004, Secor et al. 2007). The USGS Center scientists thus set the foundation for a strong and effective research program that has benefited the agencies charged with managing and restoring the system.

A strategic approach seems to have helped the Center researchers coalesce into a strong science team. The Corps and the various agencies and stakeholders benefit greatly from the presence of this stable cadre of scientists. This group provides a consistent stream of scientific information (via reports, publications and presentations -- see below), and is a resource for the many parties engaged in the restoration of the basin. Phone meetings between SEI and several external groups indicated that Center scientists are valued members of the wider science and management community. They collaborate widely with scientists from other organizations and have been willing to provide training and advice on technical and statistical issues. They helped to set up and participate in an email group to share immediate information on issues such as fish location, recapture data etc.

CSRP is currently implemented by a group of talented and highly-motivated researchers. The scientists have complementary expertise and clearly draw-on and benefit from the skills of their colleagues. There is an exemplary level of cooperation among different researchers across a broad spectrum of activities including setting project priorities, making decisions on funding allocation, coordinating sampling needs, sharing results, statistical analyses, and reporting results. Additionally, in a short time span the program has been able to create a modern, useful and integrated data-base that many programs of this size would envy.

The program is an important anchor for the Center which has invested heavily in the maintaining it. CSRP program provides around 40% of the Center's funding. (In 2007 the Corps provided $4,945,000. Funding has increased steadily since 2004 when the Corps portion of the budget totaled $1,115,000). The Center currently contributes an additional $850,000 from its own budget mainly through scientists' salaries (M. Mac, Center Director, pers. comm. 2008). However the Center's strongest investment comes from the scientists themselves, with some taking on "high-risk" research in order to address policy needs when doing so can mean fewer publications in the short term. As publications are currency in a scientific career, this is not a trivial investment.

As a USGS facility, scientists are limited in the types of grants they can apply for, and thus cannot leverage funding in ways that are available to other researchers. Instead the scientists have leveraged their program through collaborations with external scientists (e.g. at universities, and other agencies) and through their interactions with students and post-docs. Researchers are highly motivated to provide opportunities to students as well as junior scientists. There are many more opportunities to engage post-docs or graduate students in projects that would benefit the program, but the funding mechanism does not always allow for this (see next chapter). For instance, studies such as an assessment of larval development, abundance of food organisms for larvae and juveniles, and expanding certain areas of hydrological data analysis lend themselves to masters and post-doc projects respectively. (Additional suggestions and recommendations are provided in the appropriate research sections.)

PROVIDING POLICY-RELEVANT SCIENCE

As the program prides itself on being policy relevant, scientific results must be made available in a timely way. Reports and presentations are often the fastest way of getting critical information to managers and agencies. In general, the Center is doing a good job of getting information out to many decision-makers and in a timely way, but there seems to be few opportunities for more timely public outreach. Fast access to science has frequently "solved problems" for various management agencies who must chose between alternative actions. However there are instances where the Corps would clearly appreciate more immediate feedback from scientific results. Sometimes, the science does not yet have the answers. However, at other times it may be a communication failure. Scientists perceive a lack of interest or a lack of framework for making their results available. They would appreciate more regular interactions. The Corps, as the funding agency, could set up more structured and frequent dialogue to better meet its immediate needs for scientific information.

Peer-reviewed scientific publications are the hallmark of our profession's quality control. These take longer to prepare and get published. However they are given greater weight in decisions and in the courtroom (especially since passage of the Data Quality Act). This program is relatively new, having started in 2004, and the researchers are growing a strong peer-reviewed publication record. Many results have been published in the Journal of Applied Ichthyology, a periodical which has provided researchers with a forum for sturgeon biology through the World Sturgeon Conservation Society but does not have wide readership in North America. To enhance the reputation of the program, and to make the information more widely available, the panel recommends that researchers broaden the range and visibility of the journals in which they publish results. In the future, the researchers might consider submitting a conceptual publication on the working of the entire system and their investigative approach for submission to a top-level high-impact research journal.

PROGRAM TRANSITION

At the beginning of this program little was known about the pallid sturgeon. Recognizing this, the Center wisely embarked on a broad exploratory science program. Center scientists pursued several avenues of investigation and gathered important information on the biology of the species, and the hydrology of the river. This approach was successful.

Now that key approaches have been tested and much has been learned on the life cycle of pallid sturgeons, scientists are in a strong position to embark on a more focused hypothesis driven approach. The timing is ideal as there is wide interest in a more integrated and advanced research program throughout the basin. The Center is well positioned to provide scientific research as this develops.

As the Center transitions into a more hypothesis driven program and one more focused on pallid sturgeon rather than its surrogate, the shovelnose sturgeon, it will need to carefully evaluate the different components of the current research. Certain projects may need to be strengthened and others changed or completed. Specific recommendations are discussed in the appropriate chapters of this report.

STRENGTHENING THE PROGRAM

The researchers and the program struggle with several frustrations that could be easily remedied.

Scientists are deeply committed to carrying out top-level, policy-relevant science. To be effective, policy-driven science requires consistent feedback between researchers and policy-makers and managers. There appears to be a need for more timely feedback between the researchers at the Center and the Corps (funders). This sentiment was more strongly expressed by the scientists, but was also noted by the Corps (see above). Researchers would benefit from knowing how their science was received and if it was useful. They would also benefit from more direct input on information needs. Additional dialogue would allow scientists to refine their research directions and to present information in more relevant ways to decision makers. It would also provide additional incentive to the scientists to know that their research is making a difference for the species and for ecosystem restoration.

The researchers have developed a strategic approach to answering key questions on the pallid sturgeon. However, the current funding methodology does not allow for full strategic implementation. For instance, individual researchers are often unsure of the probability or extent of funding until close to the field season. Funds have to be expended by the end of the year (M. Mac personal communication 2008). Uncertainty inhibits scientists from broadening their efforts and collaborations when it might be beneficial to do so. CSRP would clearly benefit from the establishment of a more strategic funding timetable. This would allow scientists to have confidence in multi-year funding (where appropriate), and it would facilitate better planning and better use of funds, research activities, and staff. These benefits would accrue to the entire basin-wide program and not just to USGS. (We understand that the Corps is discussing a different funding approach that might alleviate some of these issues.)

It is no secret that the Center's program, when it was unveiled, was not completely well-received throughout the basin. This had little to do with the quality of the science but more with the perceived lack of coordination around the science and research efforts. For instance, several other programs on research and monitoring existed in the area (e.g. HAMP). The Corps of Engineers itself supports several different additional groups and related efforts. Because this program was developed "in a vacuum" it had to overcome several communication barriers. The Center has integrated well into the larger efforts, in part because it has maintained a discrete and identifiable program, and because of the scientists' willingness to share information and collaborate in other programs. However additional opportunities for scientists and managers to share the perspectives of their respective programs and agencies would further improve efficiency and minimize misunderstandings.

Despite the clear strengths and benefits of USGS CSRP program, it does not alleviate the need for a more basin-wide policy-driven research and funding program that is strategic, inclusive, and coordinated. The Center's program represents one part of the research effort and only a sub-section of the information needs. A more comprehensive approach would benefit all the parties, and has the potential to encourage greater collaborative solutions. Such an initiative should be based on (1) an effective communication forum and (2) adequate and strategic funding:

1. Adequate communication between agency/managers' and scientists. Effective policy-relevant science rests on understanding the needs of decision makers, and translating managers' questions into science programs. Effective use of science depends on decision-makers absorbing the information produced by the investigations and understanding how to use it appropriately. As more science becomes available, problems are solved, critical issues identified, and questions refined. Thus ongoing communication is key to a useful science program. Absent a clear process for the use of science in decision making, there exists the

possibility of science entering the policy arena in a haphazard and unstructured way. This is likely to lead to confusion and conflict over the use and interpretation of science. Indeed the history of the science-management interface in the basin is already replete with such examples. An ongoing explicit process that is transparent, facilitated, and science based is urgently needed to help resolve the broader integration of science into policy.

2. A strategic and effective funding strategy. A key strength of the Center's CSPR approach is that it is strategic and built on a conceptual framework within the limits of its scale and focus. A strategic RFP program with adaptive management and flexibility built into the effort could help the Corps and the stewards of Basin resources meet the broader goals. However, it is important for funders to recognize that research topics and RFPs need to be professionally reviewed, and that recommendations for funding and directions be provided by those with sufficient skills to understand the science and the policy-relevance of the questions.

An RFP program seems to have the support of many parties in the Basin. The Center would certainly be competitive in such an effort. However a shift to an RFP is not without some potential drawbacks. The Center's strength lies in its strategic and multi-disciplinary team approach. This framework has allowed the scientists to leverage their research and it fosters a collaborative approach among scientists within the Center as well as externally. In order to maintain the same level of productivity and quality of science, any RFP program needs to consider ways to conserve this synergy while adapting to new information needs.

This review focuses on the Center's approach and science program. Nevertheless it is worth noting that the Corps itself deserves credit for its approach. By asking, in effect, "What do we need to know and what will it take to find the answers?" and then committing resources to an excellent group of scientists, the Corps has facilitated a strong and relevant science program that benefits river restoration. In the future, strengthening interactions with the program would add to the benefit that the Corps already receives.

CHAPTER 2. SCIENTIFIC PROGRAMS

FINDINGS

The research strategy of the CERC to target questions central to current management priorities has produced valuable findings.

The approach of integrating field and laboratory studies into one research program has yielded findings that would be difficult to obtain by individual investigations.

Two defining design features of the research program are hydrologic, telemetry-linked studies and use of a surrogate species.

Documenting spawning of both shovelnose and pallid sturgeon in the Missouri River is a notable achievement, as this life event is difficult to capture in the field, particularly for less abundant pallid sturgeon.

A range of spatial scales have been explored to seek relations between sturgeon behavior and the river environment, yielding some significant findings, and much of the lower river has been covered in some way.

The use of shovelnose sturgeon as a surrogate species in the research has been productive for refining capture and tagging methods, designing efficient telemetry tracking, perfecting techniques for reproductive assessment, and other gains in study effectiveness.

RECOMMENDATIONS

Strive to move beyond a research effort that responds only to immediate management-generated questions, to provide leadership on identifying study and data needs.

Continue to develop a research strategy of telemetry-based studies and surrogate species use as a model for making scientific contributions to endangered species recovery.

Expand the river coverage included in the intensive telemetry-based studies by investigating new life stages and river habitats, as effort can now be reduced on the present priorities.

Review and communicate the uses and limitations of shovelnose sturgeon as a surrogate species for pallid sturgeon in Missouri River research and management.

Develop a phased plan for future research covering all life stages of pallid sturgeon and build in points where the concept of an early life constraint can be evaluated.

Develop a model of how habitat conditions can be linked to sturgeon movements at a range of scales with data needs across scales to identify key species-habitat combinations.

Summarize the constraints imposed and opportunities remaining for identifying species-habitat links in a system that has been greatly modified and fragmented.

Consider habitat illumination by reduced turbidity as a limiting factor on pallid sturgeon habitat, taking advantage of the USGS expertise in monitoring fine-sediment transport and resulting water quality.

STRATEGIC ISSUES

FROM DESCRIPTION TO HOLISM

The sturgeon research program of the USGS Columbia Environmental Research Center aims at determining the ecological requirements for successful pallid and shovelnose sturgeon reproduction and recruitment in the Missouri River. The research strategy has been to conduct an integrated set of field and laboratory studies on reproductive ecology, habitat requirements, and physiology. Progress on these studies has been strong, with much new and fundamental information generated on sturgeon in the Missouri River. The focus has been on studies linked to priority management issues: increased reservoir releases for spring spawning (aka, spring rise), increased shallow water habitat, and reproduction and early life in the unchannelized river reach. Key findings have been obtained for these management priorities. While study results may vary from agency expectations, they demonstrate that targeted research can inform managers about their efforts and assumptions.

The CERC sturgeon research program can now move toward a leadership role for creating management ideas and options for recovering Missouri River sturgeon. Program successes have come from an integrated approach that employed two novel components: telemetry-centered field research, and use of surrogate species (shovelnose sturgeon) for learning. Neither is new in conservation biology; however their central role at CERC for endangered species recovery research appears pioneering. For this reason, the organization of the research program and its output could be better promoted to communicate the benefits of CERC science and to contribute to endangered species research and conservation.

Telemetry is an effective method to rapidly learn about species where *a priori* knowledge is scant. As in other sturgeon research (e.g., Moser and Ross 1995), the use of telemetry has resulted in basic information on fish locations and effective sampling protocols. The CERC program has gone further and paired other study tasks and methods with telemetry for rapid information gain on targeted questions and areas. Called by CERC staff 'follow-the-fish', this research strategy has been very productive and efficient. Two expansions of this strategy now appear timely and valuable: increasing the spatial extent of telemetry-centered field research, and packaging the effort as a model for early study of wide-ranging endangered species. That is, we urge that the follow-the-fish study strategy be considered for application to other life stages and river habitats. For example, wintering sites, rearing areas, and adult non-spawning foraging range: both new life stages and river reaches. While not all stages and reaches can be simultaneously addressed, a long-range study plan can be charted for CERC research and management support. Secondly, use the Missouri River sturgeon research as a case study for endangered species recovery development. Combining the current life history model with an expanded field research strategy can be used to identify new study phases and new tiers of information need. Consider the range of species biology properties (e. g., subpopulations, habitat connectivity, delayed population responses) addressed by advanced telemetry studies of common species reviewed in Dingle and Drake (2006) and Cheke (2006). Our hope is to see productivity of the program maintained through the current well organized, team-oriented research and carried to new questions and components of the river system, while making a contribution to research and conservation of endangered species in general.

A second distinctive aspect of the CERC sturgeon research program is the use of shovelnose sturgeon as a surrogate species for learning about behaviors, habitats, and methods. We see this as another notable and novel aspect of the program. Surrogate species have been used in conservation planning (reviewed in Rodriques and Brooks 2007) for some of the same reasons involved here: a shortcut to knowledge and management guidance. While popular, the record of surrogates in conservation biology has been mixed (Andelman and Fagan 2000). The role for surrogates has been different than in the CERC program but some of the motives are similar. We urge that the CERC program develop the surrogate species approach as an option for endangered species research and identify its proper uses, benefits, and limits.

Extending the record and momentum of sturgeon research at CERC by expanding the scope would be timely and valuable. Making this program a model for endangered species research and recovery would enhance the contribution of the CERC and benefit the species research and conservation communities. In a way, we are only recommending that the well organized study program carry the team orientation forward into whole-effort reporting, publishing, and conservation leadership.

SPECIES LIFE CYCLE

A theme in the sturgeon research and the recovery management community is that spawning and possibly early larval survival is the limiting life stage for pallid sturgeon populations. This is a reasonable and justified assertion for initial studies. Spawning has been documented for pallid sturgeon on multiple occasions but occurrence of larvae remains unknown. Also, some studies have shown very short persistence of larvae. The CERC sturgeon research program is moving to increase attention on larval ecology and substantial effort is now dedicated to this life stage. This is an appropriate program change. However, we would like to see a plan for a phased expansion to all life stages and an approach to test the assumption that spawning and low larval survival limit recruitment of pallid sturgeon.

Many sturgeon populations are highly sensitive to adult mortality (Boreman 1997) and perhaps most imperiled sturgeon species primarily suffer from late life losses (Birstein 1993, Waldman and Wirgin 1998) due to harvest and incident fishing mortality. Even for listed endangered species like the shortnose sturgeon, accidental kill in fishing nets is regarded as the primary impediment for some populations (National Marine Fisheries Service 1998, 2004). Foraging range and quality, overwintering habitats, and late larval to juvenile rearing habitats also need to be considered as possible constraints on the populations of pallid sturgeon. As described below (4. Sturgeon Ecology) hatchery fish could be used as an efficient tool for studies of larval, juvenile, and pre-adult life stages. What is most needed to make a shift past the current focus is a plan for covering all life stages and a method for assessing likely constraints on population size. A comprehensive analysis of some endangered species (e.g., wolves, Carroll et al. 2006) suggest ways to view all species needs and vulnerabilities and plan to reach a point where critical life stage constraints can be tested. In other cases (Crowder et al. 1994, Fujiwara and Caswell 2001) life stages and population vulnerability were assessed relative to select threats to identify recovery potential. Given the size and importance of the CERC program, we feel the time has come to start taking a broader view of the challenge in terms of life stages and limits Missouri River abundances.

RIVER HABITATS AND THE FLUVIAL SYSTEM: INTEGRATING BIOLOGY AND HYDROLOGY

The CERC sturgeon program has made important contributions to knowledge on Missouri River sturgeon with some key findings coming from pairing studies with telemetry. Habitat analyses have mostly been organized in this manner with reach-scale physical habitat surveys sited by sturgeon occurrences. Therefore, habitat characterization has 'followed-the-fish' but accumulated to a point where a significant portion of the lower Missouri River has been characterized. Very large scale descriptions of river conditions have been made, some assumed key habitats have been mapped, and new microhabitat-scale analyses around individual fish locations are beginning. Thus, a range of scales have been explored to seek relations between sturgeon behavior and the river environment.

Despite much physical data at the reach scale, there have not been clear results linking physical conditions and sturgeon movements and locations. The use of below average velocity sites near sharp velocity gradients by shovelnose sturgeon has been described as preliminary and not shown with clear statistical support. Mapping of coarse substrate assumed to be key for spawning shows a distribution much more extensive than known spawning sites. This suggests it is not a definitive driver of spawning habitat but may be a necessary element. Overall, we judge that linking habitat to species biology remains a challenge for the program.

The Missouri River sturgeon are well recognized as commonly making long distance migrations through major regions of the river. Most sturgeon species have this behavior. Therefore, the shovelnose and pallid sturgeon orient to habitats at a wide range of scales from micro-site selection at any point in time to long distance movements to access some special set of river conditions. We feel a plan is needed to consider habitat-biology linkages at a range of scales with a justification for scheduling attention in a sequence that would test different hypotheses. Linking the physical habitat conditions to the fish under managed flows and channel structure can reveal the major impediment to species recovery - findings to date are just the beginning and do not yet provide a clear picture.

The recommendation to organize the habitat-fish research across scales from local to river-wide requires a series of decisions on priority questions. There is an enormous amount of literature on microhabitat selection in fish, and research of this type is informative of how channel changes alter habitat availability at the local scale. The management issue of increasing shallow water habitat can be addressed at this scale. Areas of fish concentration for spawning, rearing, overwintering, and possibly foraging would likely be best addressed at the reach scale. Finally, the purpose and method of orientation to river conditions underlying long distance migration may be best considered at the whole river scale. Complicating analyses at all scales is the recognition that the current river environment is far from the one that historically supported these fish. Natural, complex channel structures have been replaced by navigation channels, fish concentration areas may have relocated, and the series of different key habitats along the migratory path could now be fragmented. A key challenge then is to consider how good information can be extracted about field conditions that might be far from supportive for the species.

Issues to consider in formulating a clear agenda for linking physical conditions to species biology are diverse and challenging. More effort on modeling physical change at different scales and how change has altered habitats of importance may be most productive now. At the large scale, the extent that fragmentation may limit support for the full life cycle is a key question for species recovery. The reduced sediment load in the river and the pervasive channel navigation structures promote a set of conditions that are yet to be related to quantitative estimates of habitat change. The very clear loss of shallow water habitat by these processes may not be the most relevant perspective for sturgeon. The changing nature of the river's hydrology and reservoir-managed flow regimes further complicate analyses of habitat but modeling can be done to transcend the dynamic nature of the system. The disruption of local habitats and their availability together or in concert across distant sites are increasingly being seen as key issues for conservation of species (e.g., Becker et al. 2007) and aquatic systems (Jansson et al. 2007). The current field, analysis, and modeling capability of the CERC program are strong and adequate for more significant and tangible progress linking habitat and the sturgeon.

SPECIFIC STUDY TASKS AND TECHNIQUES

TURBIDITY

One of the remarkable properties of pallid sturgeon is their range being restricted to the turbid waters of the Missouri River and the downstream portion of the Mississippi River. Apparently, the species was never found in other readily accessible river habitats of the central US. This suggests turbidity may have been a key habitat feature defining the species range. The impoundment of the Missouri River has resulted in a major decline in the sediment load and very likely water turbidity. This would increase light penetration and illuminate a greater range of water depths. Can a brighter river environment have an impact on the survival and growth of pallid sturgeon?

While most fish thrive in well illuminated environments, there are some species that prefer low or no light conditions. Especially at the youngest life stages, some fish species avoid light or are termed negative phototaxic (Bulkowski and Meade 1983, Stearns et al. 1994, Forward et al. 1996). Although not often studied, the benefits of light avoidance are believed to be predator avoidance and increased foraging rates. This pattern has been found for some sturgeon (larval green sturgeon, Nguyen and Crocker 2007; juvenile European sturgeon, Staaks, et al. 1999; larval shortnose sturgeon, Richmond and Kynard 1995). And in the case of the Columbia River, reservoir increased light penetration in river water has been linked to reduced foraging and increased predation vulnerability in young white sturgeon (Brannon et al. 1986).

We feel this hypothesis should be considered as a possible factor limiting young pallid sturgeon survival. The river is deeper now which would provide more dark habitats, but the increased light penetration would also reduce suitable habitat area for a negative phototactic species or life stage. A first consideration of the hypothesis could be done with simple model of increased illumination and changed channel dimensions. The hypothesis also appears especially relevant to larval survival but the much more broadly distributed shovelnose sturgeon may not be a proper surrogate for this question.

SPECIES DIFFERENCES

Already discussed is the CERC's distinctive approach of using shovelnose sturgeon as a surrogate species for early learning about sturgeon in the Missouri River. While we view this strategy as promising and one to develop further, we also see the need to critically assess differences between the two sturgeon species to properly identify limits of interpretation and reveal points of differentiation. Co-occurrence of sturgeon species is common: green and white sturgeons in the Sacramento River (Schaffter 1997, Adams et al. 2007, Brown 2007), lake and Atlantic sturgeon in the St. Lawrence River (Fortin et al. 1993, Caron et al. 2002), and shortnose and Atlantic sturgeon in the Hudson River (Bain 1997). Investigations of these fish regularly show some common life history properties and some clear differences (Bain 1997, Deng et al. 2002, Kynard and Horgan 2002). Often one species is much larger and much more numerous; although not often both larger and more abundant by the same species. This appears true for the Missouri River where pallid sturgeon have long been regarded as much less abundant that shovelnose sturgeon (Bailey and Cross 1954) but clearly larger. A thorough review of the biology of both species should be used to clearly define what can be inferred from shovelnose sturgeon for pallid sturgeon. Such a comparative review would also identify hypotheses to explain differences in natural abundance and sizes for these closely related fishes.

CHAPTER 3. PHYSIOLOGY

FINDINGS

Reproductive physiology is a key component of the project with endangered pallid sturgeon. The members of the USGS reproductive physiology team are highly qualified scientists.

In collaboration with an excellent team of hydrologists, physiologists developed a unique interdisciplinary, mission-oriented project with endangered pallid sturgeon.

The more abundant shovelnose sturgeon has been used as a “surrogate” species for the development of reproductive assessment techniques, justified by the morphological and ecological similarities.

The panel notes excellent publications on reproductive assessment of shovelnose but recommends strengthening several scientific approaches and following up on new methods that are yielding positive results.

RECOMMENDATIONS

Diagnostic techniques for reproductive assessment of shovelnose can be used for the pallid sturgeon. We suggest focusing further efforts on the reproductive cycle of the target species, using wild and captive stocks of pallid sturgeon.

The proposed conceptual model for reproductive physiology of pallid sturgeon is based on the interaction of reproductive hormones, LH and MIH, and environmental cues in the late phase of reproductive cycle. For full assessment of reproductive efficiency of the pallid sturgeon, the panel recommends including the early phase of ovarian cycle and the secretion of FSH. This will be a novel development in reproductive assessment of sturgeon and may contribute to visibility of the USGS project

Research with captive stocks has contributed much to our current knowledge of reproductive physiology of fish. We recommend expanding research on reproductive physiology, using captive stocks of pallid sturgeon.

The panel notes that studies on reproductive physiology of sturgeon require adequate and stable funding support. It feels that this support is warranted and would be a strong investment as such studies provide unique insight into environmental impact on reproduction of sturgeon.

PHYSIOLOGY: OVERALL REVIEW

Reproductive physiology is an important component of the program for the endangered pallid sturgeon. Neuroendocrine reproductive axis acts as an endogenous regulator of sexual maturation and behavior, and as a mediator in the transduction of environmental cues. Therefore, secretion of reproductive hormones reveals whether or not, and at what stage, the reproductive cycle is affected by changes in environment. Changes in the environment of an impounded river may affect all phases of reproductive development, from sex differentiation to spawning. The severity of impact varies in the different sections of the river depending on suitability of spawning and rearing habitat (Beamesderfer and Farr, 1997).

The members of the USGS reproductive physiology team are highly qualified and capable researchers, possessing skill and experience in environmental and reproductive physiology of fish. They collaborate with an excellent team of hydrologists, providing a unique example of an interdisciplinary, mission-oriented project on the spawning habitat of pallid sturgeon in the Missouri River. Heretofore, most published information on reproductive physiology is based on the more abundant shovelnose considered as a “surrogate” species. The choice of shovelnose for development of reproductive assessment techniques is justified by the morphological and ecological similarities of the two sympatric species. The greater abundance and non-endangered status of shovelnose facilitates sampling and validation of non-invasive techniques by the analysis of organs and tissue obtained from sacrificed animals. The study on reproductive assessment of snovlenose sturgeon resulted in several, high-quality publications. Using ultrasonography and endoscopy, the researchers were able to identify gender, gonad volume, and stage of maturity in representative samples of shovelnose and in limited number of pallid sturgeon. The non-invasive methods were validated by gonadosomatic index and gonad histology in sacrificed fish. The analysis of reproductive stages was supported by plasma concentrations of sex steroids and yolk precursor, vitellogenin (Wildhaber et al. 2007; Bryan et al. 2007). Physiological markers were successfully used in the telemetry study, providing new information on the migratory behavior and spawning (DeLonay et al. 2007). Diagnostic techniques for reproductive assessment of shovelnose can be used for the pallid sturgeon. We suggest focusing further efforts on the reproductive cycle of the target species, using wild and captive stocks of pallid sturgeon.

The approach to studying the reproductive physiology of pallid sturgeon is driven by the conceptual model based on interaction of reproductive hormones and environmental cues. The main objective is to identify the spawning habitat of pallid sturgeon, using telemetry and spawning responses to controlled pulses of river flow (USGS Report, 2007). Gametogenesis and spawning of sturgeon are regulated by two gonadotropic hormones, FSH (follicle-stimulating hormone) and LH (luteinizing hormone). FSH plays a primary role in vitellogenesis and egg growth, and LH stimulates egg maturation and ovulation mediated by maturation-inducing steroid, MIH (Moberg et al. 1995). The increases in the plasma LH and MIH will be used as the markers of approaching spawning. This conceptual model is well suited for the telemetry study and is generally valid, except for potential difficulties in capturing transient and short-lived increase in MIH occurring shortly before ovulation. However, the measurement of LH alone will not reveal effects of altered habitat on the early phase of the reproductive cycle controlled by both pituitary gonadotropins. Changes in river temperature, water quality, and food availability may affect the recruitment and growth of the oocytes in vitellogenic phase, which is likely controlled by the FSH. The transition to vitellogenesis in sturgeon is associated with sensitive developmental events, such as mitotic differentiation of granulosa cells, synthesis of egg coat, and the concomitant secretion of the ovarian IGF-1 (Wuertz et al. 2006, 2007). The development may be arrested or delayed at this stage, affecting further maturation, synchronization of spawning, and reproductive potential of population. For the full assessment of reproductive efficiency of pallid sturgeon in the impounded river, we recommend including the early phase of ovarian cycle and the secretion of FSH in the conceptual model.

The laboratory methodology for measuring plasma steroid hormones and egg maturation assays is well established. The researchers are currently purifying LH using pituitary glands collected from shovelnose sturgeon. Purification of gonadotropic hormones for radioimmunoassay by chromatography requires 500-1000 pituitaries, which is unrealistic to obtain from the endangered pallid sturgeon. The heterologous assays based on shovelnose gonadotropins may work for pallid sturgeon, however it faces unknown cross-reactivity problem. The alternative RNA-based approach, suggested by the researchers, may be more effective and may allow development of homologous assays for the FSH and LH. It will require only a few (4-5) pituitary glands, which can be obtained from hatchery reared pallid sturgeon. This approach was successfully used to sequence FSHβ, LHβ, and common α subunits in many species, including Siberian and Russian sturgeon (Querat et al. 2000, Hurvitz et al. 2005). The production of recombinant FSH and LH and development of homologous immunoassay were reported for the Japanese eel (Kamei et al. 2003) and tilapia (Kasuto & Levavi-Sivan 2007).

Hatchery reared, captive pallid sturgeon can have enormous value for the studies of reproductive physiology, as well as for environmental toxicology, developmental biology, and conservation genetics. Captive fish can be used to develop and validate immunoassays for reproductive hormones, to examine hormonal profiles during entire reproductive cycle and spawning, and to investigate the effects of water contaminants on the reproductive cycle. Studies with captive fish have made major contributions to our current knowledge of reproductive physiology of fish. We strongly recommend continuing hatchery development for pallid sturgeon and expanding research on reproductive physiology, using captive stocks.

The researchers studying reproductive physiology of shovelnose and pallid sturgeon developed new diagnostic tools for reproductive assessment of both species. We recommend including the entire reproductive cycle of pallid sturgeon in the conceptual model, particularly previtellogenic and vitellogenic phases of the ovarian cycle. The development of homologous immunoassay for the FSH and LH will be challenging, but it will provide a powerful tool for testing hypotheses about environmental impacts on reproduction of pallid sturgeon in the impounded river. It will also be a novel development, which may contribute to visibility of the USGS project. Studies on reproductive physiology of sturgeon require adequate and stable funding support, because their success depends on the developement of new, species-specific laboratory methods, such as immunoassays for the pituitary hormones. However, such studies will provide unique insight into environmental impact on reproduction of sturgeon.

CHAPTER 4. STURGEON ECOLOGY

FINDINGS

Research on reproductive ecology, migration, and habitat requirements at CERC is being undertaken by highly dedicated and productive scientists. Team work is very evident with a strong motivation to do relevant science.

The CERC team has moved aggressively towards both innovation in technology and modeling, but has been strategic about data analysis and scientific context.

The linked reproductive-telemetry study is unique for studies on fish migration, and has contributed to important discoveries on pallid sturgeon reproduction. Similarly, a very ambitious ichthoplankton program has shown that it may be feasible to conduct early life history studies on pallid sturgeon.

Some approaches have not yet worked or been effectively deployed. These include lack of identification of pallid sturgeon larvae in the current icthyoplankton program, lack of a deployed telemetry receiver array, and unsuccessful visualization of spawning behavior through DIDSON.

With the success of pallid sturgeon collections, the panel recognized a potential conflict in the use of spawners for either research or hatchery-based restoration. Currently, the allocation of spawners towards hatchery use is given a much higher priority by the Pallid Sturgeon Recovery Team.

Shovelnose sturgeon have been effectively used in developing successful approaches related to telemetry, larval collections, and habitat choice models.

RECOMMENDATIONS

The Panel recommends that all larval collections be put in ethanol and sufficient resources be allocated towards genetic and taxonomic identification of larval pallid sturgeon.

Programmatic concerns have curtailed deployment of a receiver array. Because important benefits of a receiver array will accrue only with multi-year deployments, a different funding mechanism to CERC may be appropriate.

The DIDSON application may be important for media and public outreach, but the panel deemed it less important to the future of the research effort than deployment of the lower Missouri telemetry array and continued ichthyoplankton sampling and identification of larval pallid sturgeon.

Hatchery field experiments represent a powerful means to engage questions about larval spatial and demographic fates. In larger systems such as the lower Missouri River, larval release experiments can be simulated with hydrological models and then potential larval and juvenile nursery habitats can be "probed" through hatchery release experiments. Further, hatchery fish are efficiently deployed in a variety of lab and pond experiments related to habitat preference, feeding, and species interactions.

Although hatcheries have been a boon in provision of research animals, current demands are over-taxing the CERC telemetry program. Too few collected spawners are allowed to be tagged and returned to permit rigorous examination of flow and habitat requirements for spawning. One option might be to allocate spawners between years that are designated as entirely research- or hatchery-allocation years.

Past use of shovelnose sturgeon as a surrogate species has been very useful, but past successes strongly suggest that the program can and should place greater emphasis on pallid sturgeon reproduction and habitat requirements to more effectively utilize limited research funds.

EFFECTIVE, NOVEL AND RELEVANT COLLABORATIONS

The Center's science pertaining to ecological endpoints of Corps-sponsored contracts, that is the effects of hydrology and shoreline modifications on pallid sturgeon reproduction, is clearly motivated by a collaborative team of dedicated and productive scientists motivated to do relevant science. This is a young to mid-career, enthusiastic team trying to place exciting new results into theory and a bigger construct. Strong team work was clearly evident in research planning documents and fully collaborative research between scientists with diverse expertise in field and quantitative ecology, hydrology, and physiology. This collaboration is seen in series of co-authored technical reports and peer-reviewed publications. It is further manifest in the exemplary development of novel interdisciplinary research.

We highlight two interdisciplinary approaches that the panel recognized as evidence of success in the program focusing on telemetry. Telemetry is most often used in descriptive application – fish goes there, then there, etc. The literature is rife with examples of telemetry "fish stories." Only recently, have more ecologists worked to design, implement, and analyze telemetry data to provide population-level inferences or test critical habitat associations (Hightower et al. 2001; Heupel and Simpendorfer 2002; Crossin et al. 2007; Sivertsgard et al. 2007; Wright et al. 2007). To do so requires deliberate design elements that must be considered in advance of tagging and field work. Here, USGS introduced a telemetry study designed to confirm reproductive behavior by using physiological endpoints on tagged fish – to our knowledge this type of study is unique to the field of telemetry. Risky research, but careful planning and effective collaboration led to success. CERC scientists uncovered the so-called "apex behavior" through intensive manual tracking. By linking reproductive indices (see Chapter 3: Physiology) of reproducing fish before and after this apex behavior, compelling evidence was provided that this behavior was critically involved in spawning. Further, the ability to use both acoustic and DST tags, and then retrieve tags from spawners allowed continuous recorded temperatures and depths to be linked to all phases of migration, resting, spawning, and post-spawning. This work is very impressive. Thus, through a well conceived telemetry study (and a little self-made luck), investigators have made important discoveries about the reproductive behavior of pallid sturgeon, which might have taken another group that used more traditional telemetry approaches many years to discern.

The habitat modeling effort is the other aspect of the interdisciplinary telemetry study that has yielded results much more rapidly than the panel would have anticipated. Here, Dr. M. Wildhaber has enlisted critical outside academic support to build an innovative framework for relating two very complex datasets: the habitat assessment (mostly bathymetry attributes) with the telemetry logs of individual fish. Here again, few groups have effectively done more than provide fairly general or coarse general associations between habitat and logged positions (e.g., Secor et al. 2000a), or have done so in mostly a qualitative manner (e.g., Buckley and Kynard 1985). Here, a well reasoned hierarchical habitat choice model provides a framework for addressing difficult issues such as autocorrelation in repeated measures of individual fish and measures of non-selected habitats. Arguably, there are many ways to construct such habitat models (see Chapters 2, 5), but involvement of several outside academic scientists adds rigor and innovation to CERC's effort.

DISCOVERY AND RECENT SUCCESSES

One could argue that discoveries have been fortuitous, but there was substantial evidence that the telemetry group made their own luck through hard field work. The ability to multiply retrieve the same spawning pallid sturgeon was accomplished only after several years of intensive field work, gained knowledge on likely habitat associations, and exhaustive fishing gear deployments. Similarly, the capture of many scores of sturgeon larvae, albeit unidentified to species, is noteworthy. Previous to this dedicated and synoptic effort, relatively few larvae had been observed. In summary, the CERC has successfully shown that in the lower Missouri River, they can engage most, if not all, critical life history stages of this endangered species.

RESEARCH GAPS, HATCHERIES, AND FUTURE DIRECTIONS

Some technologies and studies have been less successful in the program of research designed to better understand reproduction and early life history of pallid sturgeons. First, despite a very synoptic ichyoplankton field and laborious sorting efforts and the identification of dozens larvae of the genus *Scaphyrinchus*, we still don't know if any pallid sturgeon reproduction is resulting in larval production of pallid sturgeon. Regrettably, ichthyoplankton samples were fixed in formalin, which precludes subsequent definitive classification of pallid versus shovelnose sturgeon using genetic markers. Because shovelnose sturgeon are much more abundant in the lower Missouri, it is impossible to attribute unidentified larval sturgeon larvae to the rarer pallid sturgeon species. Formalin fixation, does not permit subsequent genetic identification, but was deemed necessary due to high detrital and vegetation loads and the difficulty in identifying larvae preserved in ethanol. Formalin fixation is a convention designed for fish collections and museum-quality specimens (e.g. Snyder 1983), but this convention is not absolutely needed in targeted research efforts (e.g., Secor and Houde 1995; Carlsson et al. 2007). Indeed, many coastal systems carry much higher detrital loads and diverse icthyoplankton fauna and the convention in marine ichthyoplankton studies is for ethanol preservation. Further, sturgeon larvae are relative large and easily sorted from other ichthyoplankton, curtailing the need for formalin fixation. In summary, an important aspect of USGS's research is to definitively determine through genetics that pallid larval production continues to occur in the lower Missouri. To meet this research gap, the panel strongly recommends preservation of samples in ethanol and that sufficient resources are allocated towards genotyping sturgeon larvae. Further, the taxonomy of larval pallid and shovelnose sturgeon may deserve another look. For instance, the taxonomic discrimination of the larval Moronidae striped bass from white perch has a long history in the literature but was only recently solved in a definitive manner (Waldman and Andreyko 1993).

An unmet goal of the research program is to establish an array of receivers, which will permit continuous monitoring of electronically tagged sturgeons by receivers spread at ~50 mile intervals in the lower Missouri. The array will represent an important infrastructural development, advantageous in (1) sampling under-represented seasons and regions; (2) assisting field crews in targeting their relocation efforts and potentially relieving some need for continuous deployment of crews throughout the river; and (3) providing long-term synoptic tracking of pallid sturgeon that field crews cannot accomplish through manual tracking. In terms of outcomes, an array will allow discovery of broad-scale river-use patterns (see Chapter 2) that are not possible through intensive relocation efforts and also permit more efficient deployment of manual tracking crews. Although array receivers and mooring hardware have been purchased, deployments require dedicated efforts in terms of validating receiver capabilities, providing secure receiver locations, and then the assurance of multi-year support needed to obtain sufficient data from the array. The array will be best suited for studies involving multi-year tags to describe major portions of the pallid sturgeon's life cycle (e.g. Erickson et al. 2007). It also represents an investment in infrastructure that must be maintained during that multi-year period. For instance, in a 1-yr study one cannot deploy dozens of receivers, tag and monitor fish over a 12 month cycle and then retrieve all the receivers. The array will principally yield research dividends if it is deployed over a multi-year period. Because the lead scientist cannot obtain such a commitment, he has refused to deploy the receivers. Despite the strong advantages a receiver array would provide goals related to understanding reproduction and habitat use by pallid sturgeons, the panel is sympathetic to this decision not to proceed.

The success of being able to reliably relocate and recapture spawning pallid sturgeon has created new research opportunities, but it has also raised a possible conflict between research and hatchery-based restoration. USFWS, which oversees the collection permit requires the telemetry program to turn over most of the collected spawners to state and federal hatcheries. Only recently, the panel learned, was a coordinated Missouri River hatchery-based restoration plan implemented. Although beyond the charge of this current review, the hatchery program did not appear to have the same degree of planning in terms of genetics, evaluation, and regional coordination as other hatchery programs devoted to restoration of endangered species (Secor et al. 2007). The panel felt that demands made by USFWS and hatcheries placed an undue burden on a program that is primarily focused on research. While, it is laudable to take advantage of the recent ability to provide ripe adult pallid sturgeon to hatcheries, the panel urges more careful consideration of the role of USGS in the provision of spawners and more deliberate consideration of their allocation to hatchery production.

A principal goal of the restoration program and research supporting it must be to allow for natural reproduction; removing spawners of a rare species can potentially curtail reproductive success by the remaining wild spawners (Secor et al. 2000b). Insufficient information exists to determine whether hatchery released pallid sturgeon will undertake natural reproduction. Evidence does indicate that for Atlantic and Pacific salmon, reproductive success of hatchery fish in the wild can be low (Fleming and Gross 1997). Further, reproduction by hatchery fish can interfere with wild reproduction (Araki et al. 2007). Again, such hatchery issues for pallid sturgeon merit separate review.

The panel notes that the current hatchery requirement for the majority of pallid spawners is an impediment to improved understanding on the reproductive behavior of pallid sturgeon in the lower Missouri. By permitting only 2-3 female pallid to be retained in the river for tagging, while potentially dozens go to the hatchery all but guarantees that flow and habitat requirements for spawning will never be understood in a quantitative manner due to insufficient statistical power. The panel suggests that USGS, USFWS, and the Pallid Sturgeon Recovery Team may wish to consider not doing partial allocations each year but allocate "research years," where hatchery production does not occur on that year's collected spawners but all collected spawners are allocated towards tagging and tests of flow/habitat/spawning associations. Because spawners can be repeatedly collected over years, this allocation scheme should ensure that there remains sufficient opportunity to prioritize "hatchery years" that support conservation goals that safeguard the species against extirpation.

The panel noted a very strong priority by CERC to observe and document the spawning event itself. In sturgeon studies, this is typically achieved indirectly through egg collectors (buff pads) placed near the site of spawning. However, the Missouri is a very large river and this method is unlikely to be successful. Indeed initial attempts have been unsuccessful. The program is deploying and considering innovative imaging technology such as DIDSON to provide a "video" record of spawning. Such imaging could be a dramatic documentation of pallid sturgeon spawning but is likely to be a "one-off," unlikely to be replicated and outside an experimental/quantitative framework. Such verification is helpful and yields potentially high impact with the media, which certainly cannot be discounted (think for instance, of a video clip of an ivory-billed woodpecker). Still, the panel cautions USGS scientists not to over emphasize the spawning event itself – it may prove illusive. Further, the research group has already learned central elements of the "apex behavior" upon which they can more productively build flow and habitat relationships. One such avenue is through modeling larval fates.

The team of CERC scientists has the opportunity now to engage a critically important question: based upon verified spawning locations, what are the likely spatial fates of larvae and young-of-the-year juveniles? Already in the upper Missouri, an exciting experiment is being undertaken releasing hatchery-produced larvae and trying to match observed fates with predicted ones. Hatcheries are well employed in such activities and the panel learned that it was now possible for hatcheries to produce hundreds of thousands of larvae, which represents a remarkable advancement in pallid sturgeon hatchery production (recognizing that such progress does require wild spawners – see discussion above on research vs. hatchery allocation). The lower Missouri is a much bigger system than the upper Missouri and it is unclear whether an actual hatchery release experiment would be feasible. Secor and Houde (1995) provided back-of-the-envelope calculations on how to determine the likely success of larval mark release experiments in closed and open systems. Empirical evidence supports that such experiments can occur in moderately large riverine/estuarine systems. For instance, studies on Chesapeake Bay striped bass larvae (Patuxent and Nanticoke Rivers) demonstrated the feasibility of larval releases that were supported by moderate hatchery production levels (<5 females) and showed how larvae could be used as environmental probes relating vital and spatial fates to highly variable estuarine conditions (Secor et al. 1995; Secor and Houde 1998). Even if such experiments prove infeasible for the lower Missouri, hydrological transport models can still be applied to spawning locations to predict likely larval settlement areas and YOY nursery habitats (e.g., Bulak et al. 1997). These regions can then be the target of hatchery larval or juvenile release experiments to determine whether such habitats can support recruitment. The panel strongly encourages consideration of hatchery-based mark-release experiments in support of improved understanding of flow and habitat requirements during the first year of life.

In addition to release experiments, hatcheries can also support critical laboratory and pond experiments. Such experiments are now underway, but several given priority by the panel included habitat preference studies by juveniles, studies on electronic tagging retention and effects, effects of turbidity, and investigations on feeding preferences and interactions between pallid and shovelnose juveniles.

Programmatically, the CSRP has lessened risk by considering shovelnose sturgeon as a surrogate species for pallid sturgeon. This has merit in testing and evaluating approaches ranging from physiological end points, to collection and tagging procedures to developing complex habitat choice models. Past successes by the research program have been due in large part to this surrogate species "option." At this juncture however, the panel felt that, in most cases (but see Chapter 4), central research approaches had been sufficiently vetted with shovelnose sturgeon. Therefore, programmatically, the panel recommends more aggressive pursuit of a program of research that is centered on pallid sturgeon in both the field and the laboratory. This will result in more dedicated resources to the central issue of pallid sturgeon reproduction, habitat requirements, and life history. Further, based upon literature on rivers that support other sympatric sturgeon species, there is reason to expect important differences exist between shovelnose and pallid sturgeon in their ecology and habitat requirements (see Chapter 2). Increased/exclusive emphasis on pallid sturgeon should be considered for (1) the telemetry program; (2) the larval collection program; and (3) the habitat modeling program. Still, continued use of shovelnose sturgeon in studies on reproduction/physiology and habitat modeling was supported by the panel (Chapters 3 and 5).

CHAPTER 5. HYDROLOGY AND GEOMORPHOLOGY

FINDINGS

CERC has invested a skillful, energetic team of physical scientists in the sturgeon project, and they have made an exceptional effort to conduct studies of physical habitat characteristics in a manner that is tightly linked to the fish studies.

Much progress has already been made in high-quality measurements of environmental conditions within the heavily altered Missouri River channel and to model the details of flow conditions over spawning habitat for a range of discharge.

Geomorphological studies of spawning gravel distributions, shallow water habitats, and floodplain channels are broadening the information base for future studies of other life stages of the sturgeon.

The interdisciplinary nature of the USGS, its ability to invest first-rate scientific talent and equipment, its network of science centers, and its unique relationships with state agencies gives them a powerful advantage in providing conceptual, logistical, and analytical leadership for large-scale, interdisciplinary and inter-state assessments.

RECOMMENDATIONS

The excellent work already done in topographic survey of channels and in flow modeling could be extended to form the basis of experimental studies of the dispersal and survival of the fish at post-spawning life stages.

The group has a very good record of producing scientific publications, and surveys and data reports for planning, but provision of more postdoctoral personnel to assist with analyzing the rich data stream being produced would extend the group's productivity and usefulness to management agencies.

HYDROLOGY AND GEOMORPHOLOGY: OVERALL REVIEW

The hydrology and geomorphology component of the sturgeon project demonstrates how a high-quality scientific approach to habitat characterization can be efficiently combined with tracer studies of habitat use by the sturgeon. The techniques for surveying the channel topography, channel-bed grain size, and water velocity field that are thought to affect sturgeon behavior are being combined with state-of-the-art, two-dimensional flow modeling for characterizing habitat quality (Johnson et al., 2006) and for establishing a process-based approach to understanding engineering impacts on the sturgeon life cycle. The flow modeling allows the researchers to interpolate between the already dense measurements, and also to extrapolate to unsampled flow conditions and hypothetical flow management scenarios. The studies of bed changes during sediment transport at various flows yields information on how spawning conditions might vary with flow changes through a season (Gaeuman and Jacobson, 2006, 2007a, 2007b). Quantitative relationship of the flow to habitat quality allows one to quantify the role of managed flow regimes (Jacobson and Galat, in revision) and eventually long-term excursions of flow from normal values during persistent droughts. The results also prepare for the day when simulation studies of fish habitat use at various stages of the life cycle can supersede purely statistical associations.

The group has also developed ideas for extending high-resolution physical habitat studies to post-spawning stages of the sturgeon life cycle as they are affected by natural and managed flow variations and especially by the availability of shallow water habitat along channel margins, in tributaries, and in floodplain channels, -- building on the group's earlier work funded from other sources (Jacobson et al., 2001; 2006). For example, the group's monitoring and modeling of velocity fields prepare it well to participate in any future experimental field studies of larvae dispersal in the Lower Missouri (similar to studies already conducted by USGS in the upper river). Recent surveys of channel margin shallow-water habitat and simulation modeling of the amount of such habitat at various flows in the pre-engineering era (Jacobson and Galat, 2006; Johnson et al., 2006) provide a basis for examining options for habitat restoration. The group's surveys of newly engineered chute cutoffs across the floodplain establish a baseline for understanding the evolution and life span of these features and also a template for biological surveys of their potential role in food production and off-channel refuge. Although funding and logistics are not yet targeted on whole-river, whole-life-cycle studies of the sturgeon, the physical habitat group is well placed to extend their surveys and modeling in support of biological studies of post-spawning life stages. An example is the group's survey of spawning habitat availability along the entire lower Missouri (Laustrup et al., 2007).

The efficiency of integration and the productivity of the physical and biological studies results from the ability and willingness of the USGS to assign to the project productive, flexible, problem-solving scientists with an extraordinary range of experience in large-river hydrology and geomorphology related to biological and resource management issues. The physical scientists are strongly motivated and experienced in collaborating with biologists to develop conceptual models of the interdisciplinary nature of the problem at hand (Wildhaber et al., 2007), and to mount high-quality field studies that incorporate cutting-edge technology. Thus, the physical aspects of the habitat are not studied in isolation but are closely integrated with the biological studies to produce data that can be immediately integrated, for example, into the statistical analysis of how fish utilize the available habitat within a reach. Unlike many other studies of physical channel habitat characteristics, USGS scientists have been able to plan studies that take account of the fact that the sturgeon life cycle takes place in flowing water that varies in depth, velocity, and turbidity with season and regulation over spatially variable channel-bed substrates that also change character with flow regime and sediment supply. They are executing or planning studies relevant to the processes of spawning site selection, egg deposition, larvae release, dispersal and maturation of young, and feeding and growth. It is the tightness of the fish-physics linkages and the thoroughness of data collection and physical habitat modeling that yield a distinctive study that few institutions could match. The Survey's interdisciplinary team brings far-sighted conceptual leadership to the study of sturgeon biology and habitat, and is particularly well prepared through the Survey's network of science centers to integrate information gathered by the Survey's hydrometric network and by State resource agency scientists along various river reaches. It is hard to imagine such an integrated study being carried out by any other agency or consultant without the Survey's range of expertise and degree of integration.

The work has produced publications in the scientific literature (*Journal of Geophysical Research*, 2006; *Journal of Applied Ichthyology*, 2007; *Journal of Hydraulic Engineering*, 2007; *Geomorphology*, 2006) as well as US Geological Survey publications and conference proceedings. Some of the team's published research, supported from other funding sources enhance and leverage the research funded by the sturgeon project (e.g. Elliott and Jacobson, 2006; Jacobson et al., 2007; Jacobson and Galat, in revision; Jacobson et al., submitted).

The group has combined an admirable amount of publication with extensive field surveys, but there is much to be gained by enhancing the group's analytical capacity by providing it with postdoctoral support for intensifying data analysis, including extending the surveys throughout the channel to enhance a larger-scale, whole-river perspective on habitat characteristics and use throughout the sturgeon life cycle.

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APPENDIX A: AGENDA

Sturgeon Research Review

Agenda (all times approximate)

January 31:
10:30 Introduction of Research Team, Review Panel

10:45 The Missouri River – Jacobson
1. Physical Setting – focus on lower River
2. Hydrograph
3. Biology

11:15 Background information on USGS/USACE Sturgeon research – Mac
1. How it started –CERC and USGS role
2. History of River Management
3. Role in Biological Opinion
4. Budget History
5. Processes and Agency Interactions
6. Acrimony in the Basin and MRRIC

12:00 – Lunch – Poster viewing

12:45 Sturgeon recovery: basin-wide - Delonay

1:30 Propagation strategies – FWS (Jordan)

2:00 – Learning the Life History of the Scaph. Sturgeons - Delonay
1. Background, including Surrogacy
2. Methods
3. Telemetry Studies
4. migration behavior
5. Spawning
6. Results and Observations
7. Next Steps

3:15 Break and optional tour

3:30 – Site specific Studies - Simpkins

1. Background
2. Methods
3. Spawning Behavior
4. Habitat Use
5. Larval Sampling
6. Results
7. Next Steps

4:30 Discussion and Day 1 wrap-up

Evening Social Event - TBD

Feburary 1:

8:00 – Habitat relationships - Jacobson

1. Background – Missouri River Habitats
2. Methods
3. Habitat availability
4. Habitat selection
5. Results
6. Next steps

9:00 The BioP – FWS - Scott

9:30 Break

9:45 Reproductive Physiology – Papoulias

1. Background – hormone model
2. Methods
3. Hormones studies
4. Gauging readiness to spawn
5. Environmental Cues
6. Results
7. Next Steps

10:45 Research Needs Workshop Efforts - Korschgen

11:30 Field trip/ lunch

Lunch will take place at a river-side, blufftop restaurant that enables some long views of the river. We will travel to Overton Bottoms by bus and look at a sight where shallow water habitat restoration efforts have occurred. We will also travel to another site further downriver and look flood dynamics, and other shallow water habitat efforts.

During the trip, we will be on a bus a making presentations on different river topics.

Evening: Panel Meeting

February 2:
8:30 Modeling – Wildhaber

1. Conceptual Model\
2. Population Model
3. Next Steps

9:30 Information Management – Chojnaki, Korschgen

10:30 Small Group interactions

Physiology – Papoulias - Doroshov

Fish guys – Delonay, Simpkins, Wildhaber - Bain and Secor

Habitat – Jacobson – Dunne

Management –Korschgen, Mac - Brosnan (Courtney).

12:00 Lunch / Panel Meeting

February 3:
TBD